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Title: Momentum Users Guide

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Momentum Users Guide

Introduction

Momentum is software, written Mark Smith-Nelson, to analyze neutron list-mode data [1]. It contains some features specific to the MC-15 and NPOD neutron multiplicity counters. The MC-15 (Figure 1) contains 15 ^{3}He tubes and electronics for recording, in list mode, the time and tube number for each neutron detection. The data depends on many different parameters, including the source material type, source mass and enrichment, alpha ratio, detection efficiency, and multiplication. If some minimum number of these parameters is known, then Momentum can be used to calculate the remaining parameters. For example, if everything is known except the mass and multiplication, then Momentum can be used to calculate these two parameters. The Momentum calculations are based on the Hage-Cifarelli analysis [2,3].

Figure 1. MC-15 neutron detector.

Operating Procedure

The main steps are numbered. The steps (in red) are followed by descriptions of the parameters that can be accessed via the various screens.

Starting Momentum

1) Open the executable program.

All of the analysis and screen shots in this report were done with Momentum Version 0.45.7 (64 bit). Figure 2 shows the first screen after Momentum is opened.

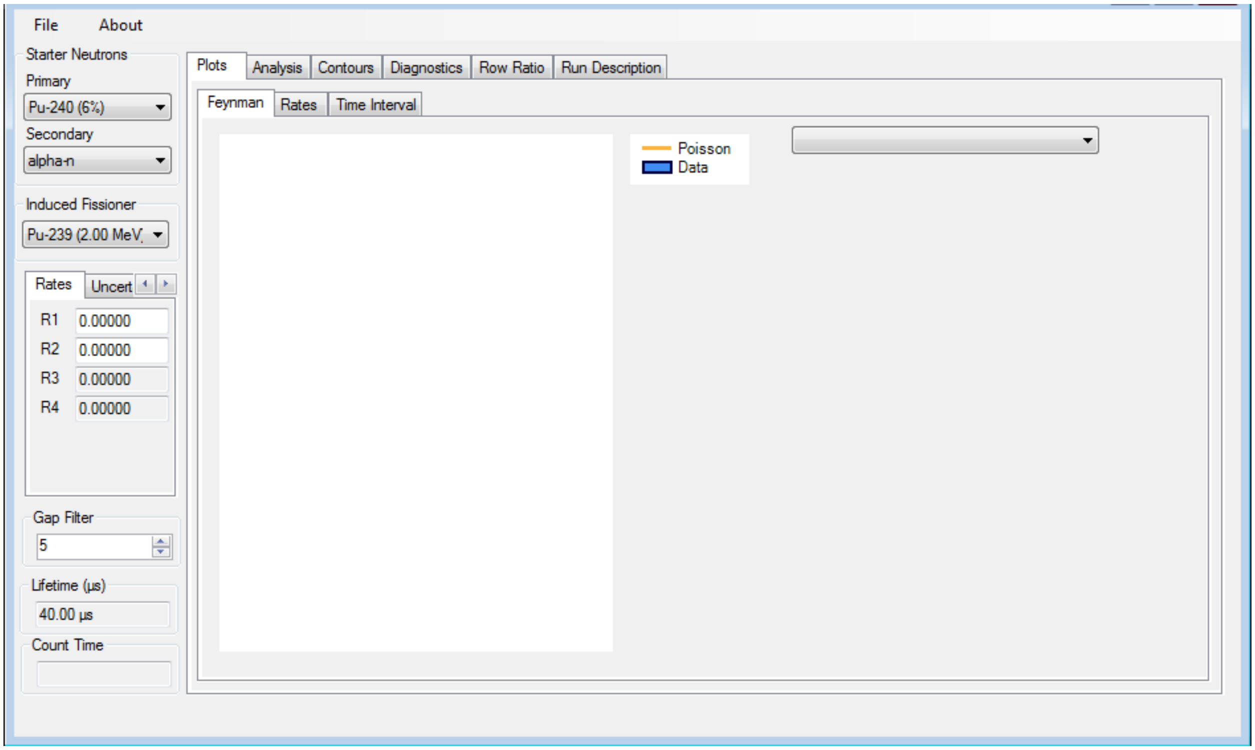

Figure 2. First screen after starting Momentum.

Opening Data File

2) For analysis of passive data, use "File" (top left in Figure 2) to locate and open an MC-15 lmx or NPOD .dat file. For analysis of active data, open the xml file generated by the program FeynView. The file can also be dragged and dropped in the starting Momentum window (Figure 2).

After opening a passive data file, the Process List Mode Data screen is displayed as shown in Figure 3. The data here and throughout this report are for the bare BeRP ball (file 2017_01_24_155316.lmx) until the section on other examples near the end of the report. Opening an active .xml data file will skip the Process List Mode Data screen and go to the screen shown in Figure 4 because the processing has already been done by the FeynView code.

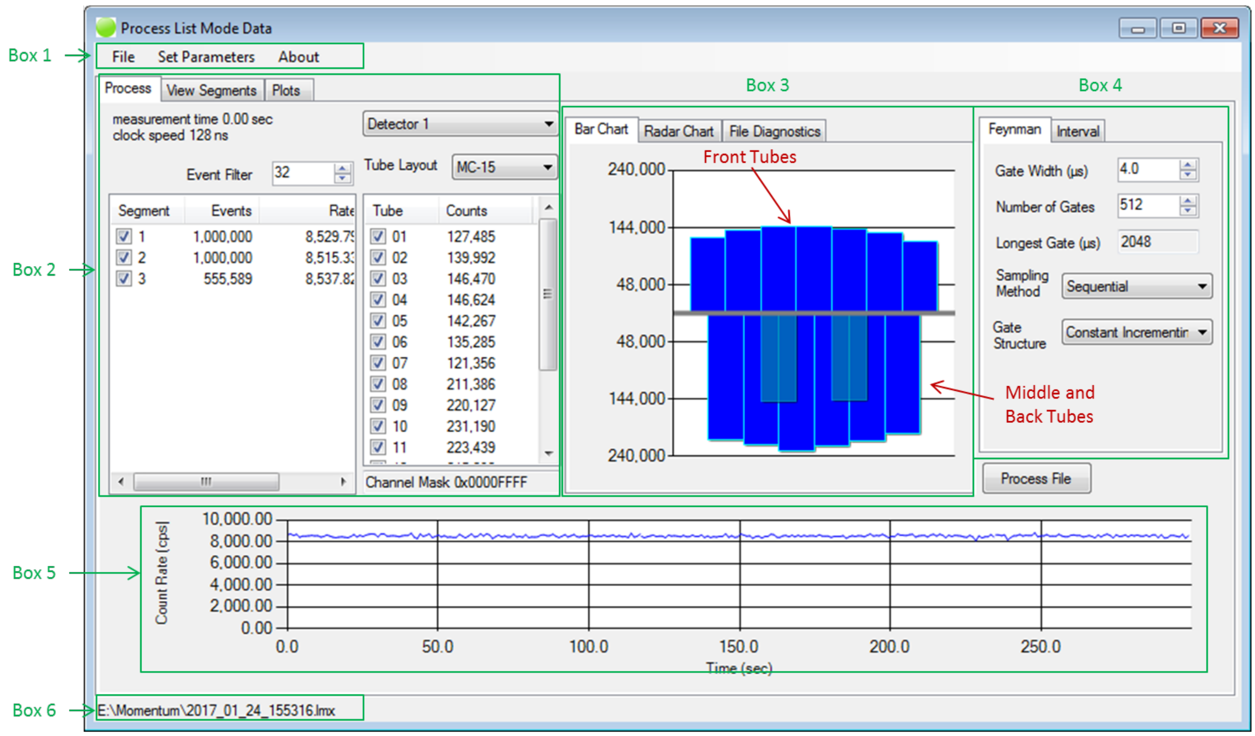

Figure 3. Example of Process List Mode Data screen after opening a passive data file for the bare BeRP ball. The green boxes have been added to refer to parts of the screen in the discussion below. The notes in red have also been added.

Preparing for Processing

3) Review the information on the Process List Mode Data screen (Figure 3) and correct if needed. In particular, review the segment event rates, tube counts, bar and radar charts, and Count Rate plot. The segment event rates should be approximately constant; the tube counts profile should be symmetric; and the Count Rate history should be constant. Bad segments and tubes should be unchecked before processing. Using the default Feynman parameters is recommended for the initial processing.

More information about the various drop-down menus, tabs, entry boxes, displays, etc. in the Process List Mode Date screen is provided in the following discussion. The parts being discussed are indicated by green boxes in Figure 3.

Box 1 in Figure 3

File

Allows the present data file to be saved as a list mode file (lmx) or Condensed file (cmx).

About

Provides the version number, author, build date, and build time.

Box 2 in Figure 3

Detector Menu
Provides a choice of which detector data is listed in the Tube-Counts box and plotted in the Charts.

Event Filter
Sets the maximum allowed number of tubes with simultaneous detections. This allows rejections of some background and cosmic events during the processing. The default is 32.

Tube Layout
Controls whether the charts are for the MC-15, nPod, or unspecified.

Segment-Events-Rate Window
For the MC-15 lmx files, the 1,000,000 event segments with rates are displayed. For the NPOD .dat files, ~83,000 event segments with rates are displayed. The user should check that the rates are all similar and uncheck any segment that appears to be anomalous.

Tube-Counts Window
The number of counts in each tube is displayed. The user should check that the counts as displayed in the charts are as expected and uncheck any tube that appears to be anomalous.

Box 3 in Figure 3

Bar Chart Tab
A bar plot of the counts in each tube. Note that the front seven tubes are plotted above the middle of the plot, whereas the other middle six and back two tubes are plotted on an inverted scale below the middle of the plot. The count profile should be symmetric for most systems. The user should uncheck in the Tube-Counts window in Box 2 any tube that appears to be anomalous.

Radar Chart Tab
A plot, similar to a polar plot, of the counts in each tube. The user should uncheck in the Tube-Counts window in Box 2 any tube that appears to be anomalous.

File Diagnostics Tab
Provides the clock speed and channel mask.

Box 4 in Figure 3

Feynman Tab/Gate Width
Sets the gate width for the Feynman binning of the data. This is both the minimum gate width and the step size. The default value that is initially displayed is recommended for the initial processing.

Feynman Tab/Number of Gates
Sets the number of gates for the Feynman binning. The default value that is initially displayed is recommended for the initial processing.

Feynman Tab/Longest Gate

This is the product of the (gate width)*(number of gates) and is calculated by the program.

Feynman Tab/Sampling Method

Allows selection of one of four methods for binning the data: Sequential, Incrementing, Random, and Expanding. Sequential or random is recommended based on a study of these methods [4].

Feynman Tab/Gate Structure

Constant Incrementing is recommended although other choices are available.

Interval Tab

Checking the Create Rossi box will create a Rossi analysis. The Count Rate Interval specifies the interval to use for the Rossi analysis.

Box 5 in Figure 3

A plot of the count rate history. If the count rate is not constant, unchecked the bad data in *Segment-Events-Rate* window and/or the *Tube-Counts* window, both in Box 2.

Box 6 in Figure 3

Location and filename of the file that has been opened.

Processing the File

4) Click on the Process File button in Process List Mode Data (right side of Figure 3). This will create the Feynman histograms and perform the Rossi alpha and time interval distribution binning for the data with the parameters that have been selected.
5) Save the results (recommended). A small window will be display that allows the results of the processing to be saved as .csv, xml, and 2A.log files.
6) Close the Process List Mode Data window (Figure 3). A screen with the results of the processing will be visible (Figure 4). The format of this screen is similar to the format shown Figure 2 but now includes the results of the processing.

   Note: If an active data xml file was opened in step 2, this screen (Figure 4) will be displayed without processing in Momentum because the processing was done in FeynView.

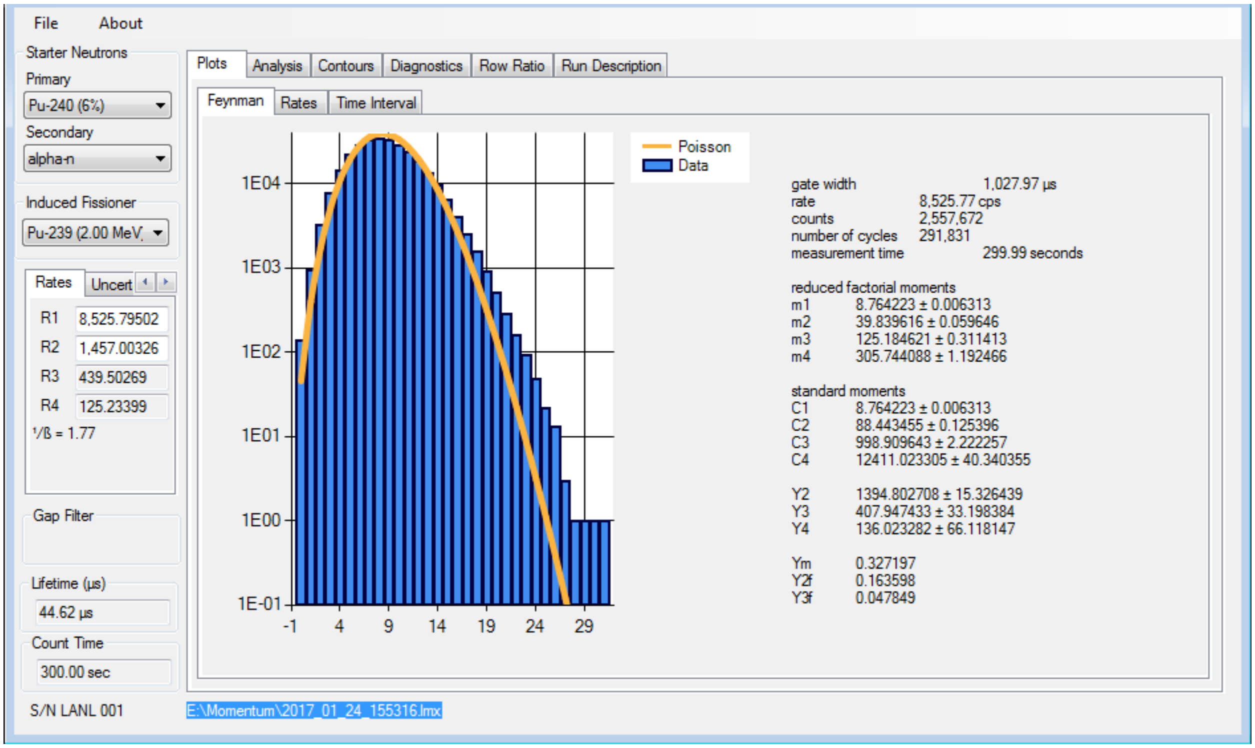

Figure 4. Example of Momentum screen after processing data.

Plots

Plots/*Feynman*

7) Check for multiplication. If there is multiplication, the Feynman histogram exceeds the Poisson distribution on the right side of the histogram and $Y_2 > 0$. However, note that Y_2 is often slightly > 0, even for sources (See Figure 19). Also check for isolated counts on the right side of the plot that may be due to cosmic-ray spallation. These can be excluded from the analysis with the Gap Filter setting.

The example in Figure 4 shows clear signs of multiplication. The right side of the Figure 4 shows the gate width (initially set to the midpoint between the shortest and longest gate widths), reduced factorial moments, standard moments, and other parameters from the processing. See Reference [5] for definitions of these parameters.

Plots/*Rates*

8) Optimize the fits to determine the detector lifetime.

The singles, doubles, triples, and quads are plotted vs. the gate width. Figure 5 in which the "Doubles" tab has been selected shows an example of Y_2 vs. the gate width. The right side of Figure 5 shows information about the fits to the data. The number of detector lifetimes to use in the fit is internally set to 2. The Fit Offset (index) allows the data near 0 gate width to be not included in the fit, and the position is indicated by a red dot on the plot. Checking the Find Offset Automatically box is recommended, but varying the Offset manually might improve the fit is some cases. The Fit # Rates should be left at 3.

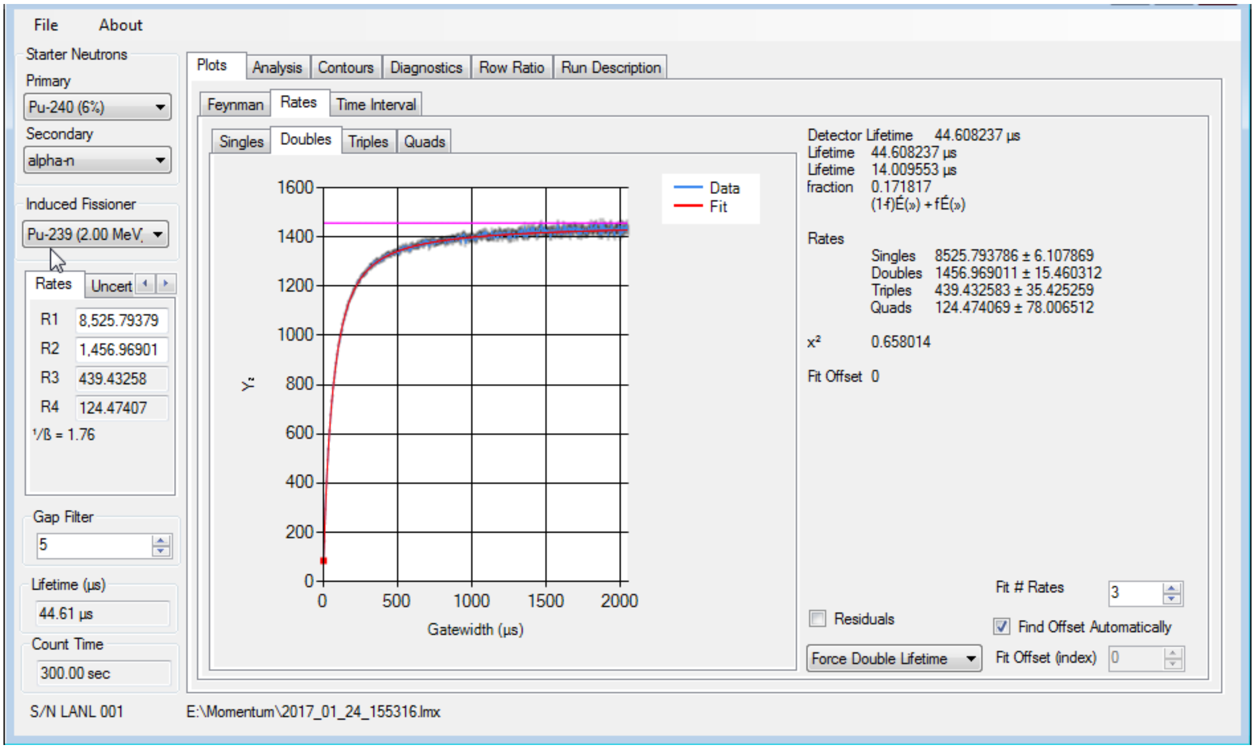

Figure 5. Screen showing an example plot of Y_2 vs. the gate width.

Plots/*Time Interval/Rossi-Alpha*

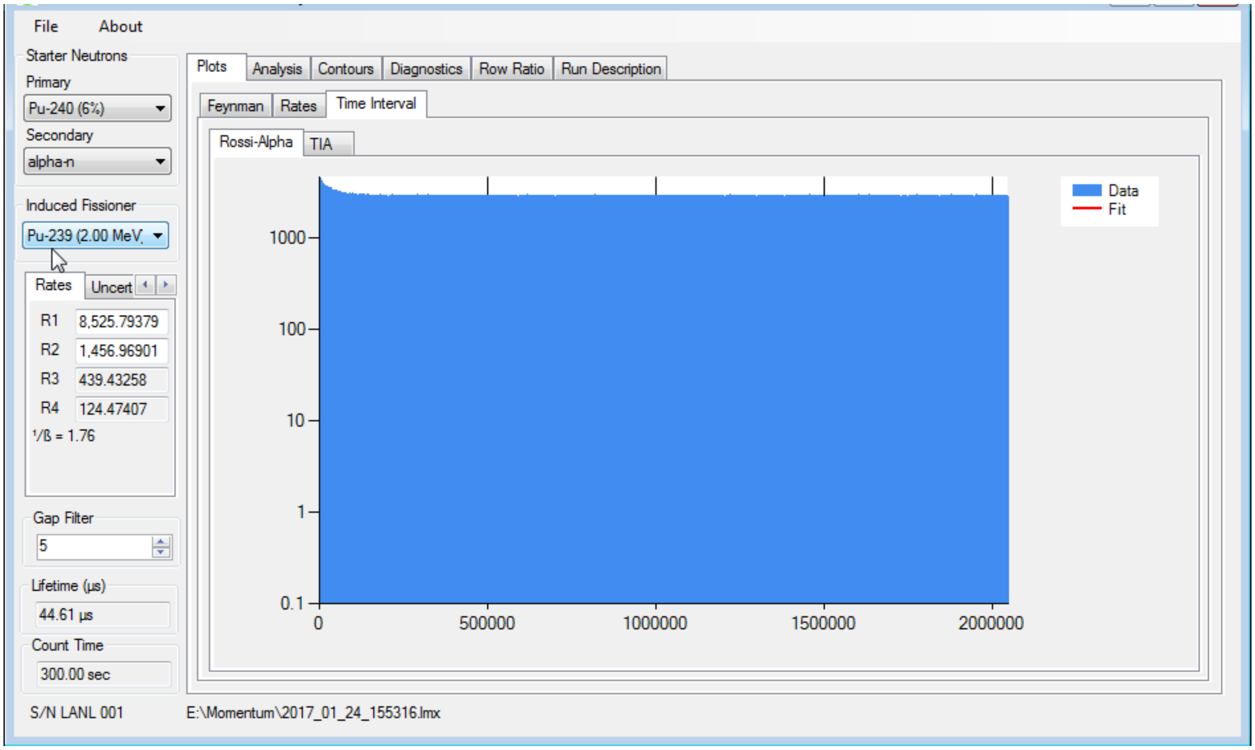

Figure 6. Screen showing an example of a Rossi-Alpha plot.

Plots/*Time Interval/TIA*

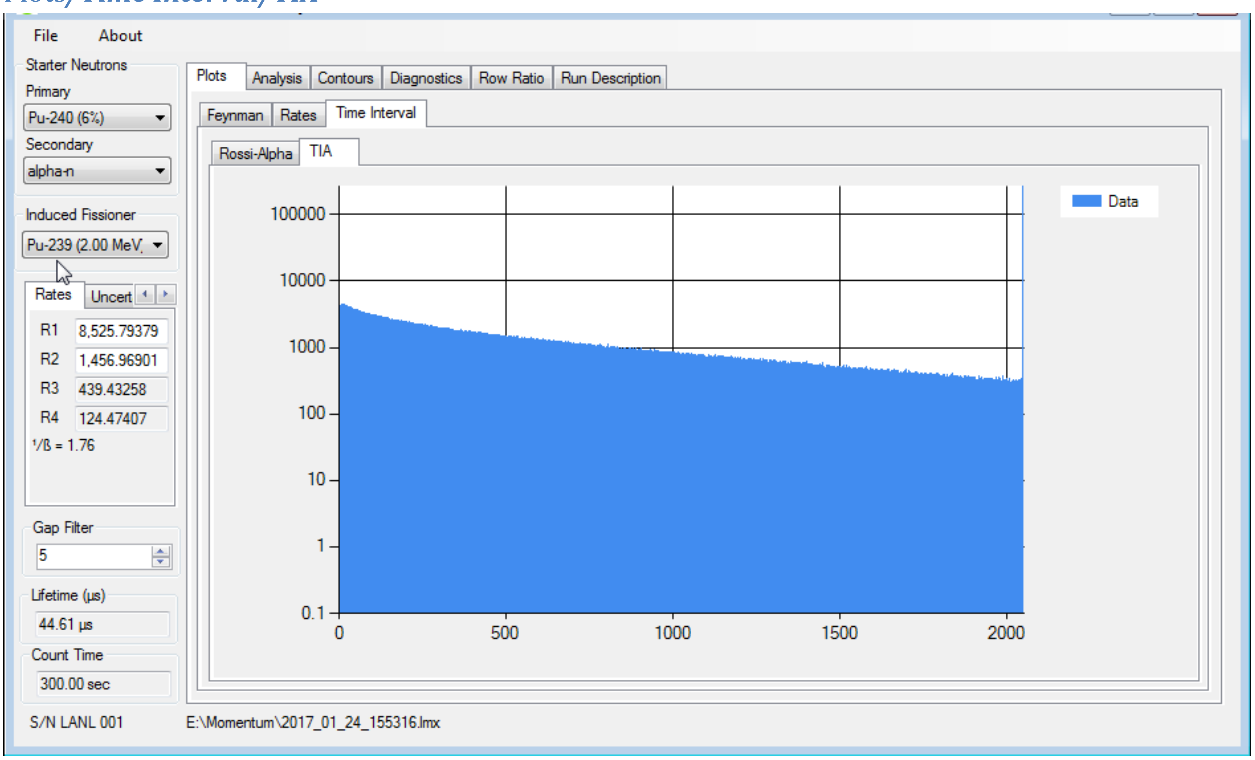

Figure 7. Screen showing an example of a TIA plot.

Analysis

9) Click on the Analysis tab, and the screen shown in Figure 8 will open.

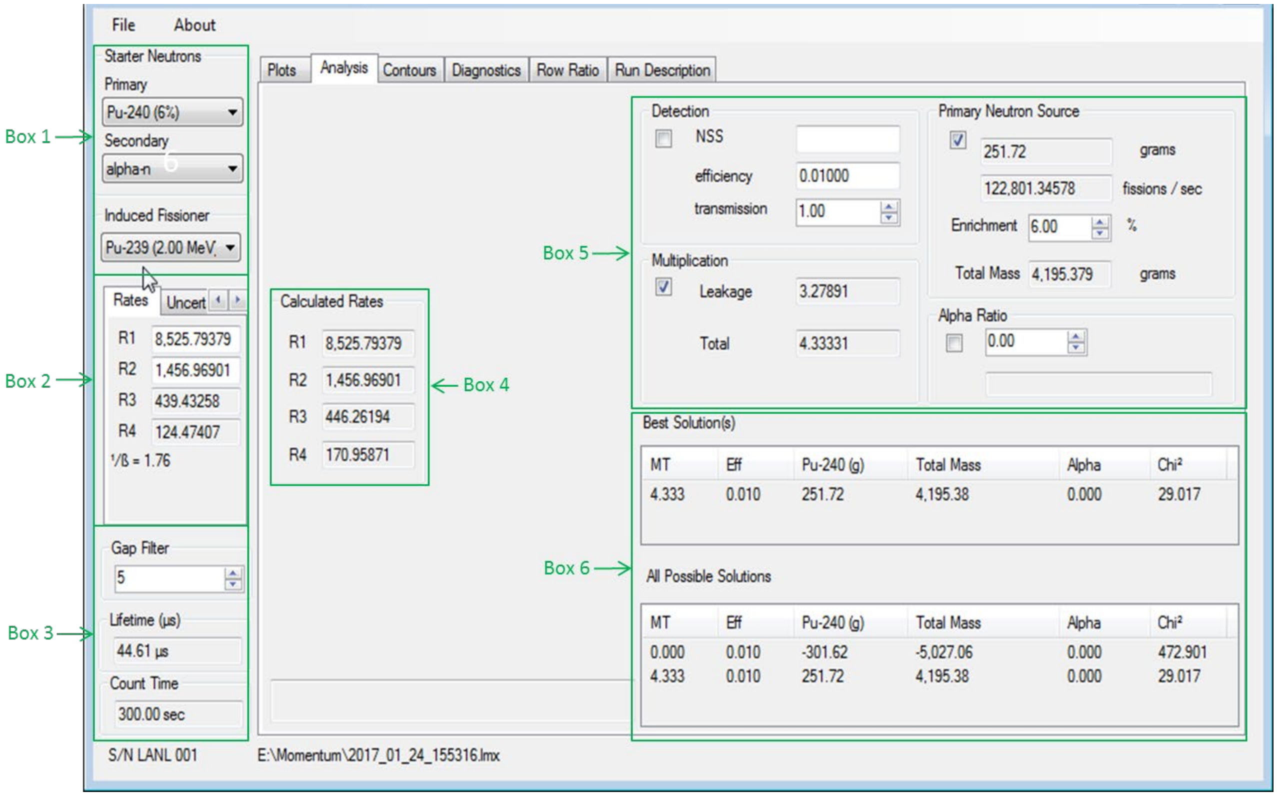

Figure 8. Analysis tab screen. The green boxes have been added to refer to parts of the screen in the discussion below.

Box 1 in Figure 8

10) Select the starter neutrons. These choices are used in the analysis.

Starter Neutrons/Primary Menu

Allows selection of the primary source of starter neutrons: Pu-240, Pu-240 (6%), Cf-252, U-238, or alpha-n. This information must be known for input to Momentum and might be based on gamma spectroscopy. For passive data, select one of the five choices. The default is Pu-240 (6%), and this is appropriate for the bare BeRP ball. For active data, the starter neutrons are the random delayed neutrons between neutron generator pulses. The alpha-n choice provides random neutrons and is the best choice in the present version of Momentum.

Starter Neutrons/*Secondary Menu*

Allows selection of the secondary source. The choices are the same as for the Primary box, and again, the information must be known for input to Momentum. The default is alpha-n, which is appropriate for the BeRP ball. Again, alpha-n is the best choice for active data.

Starter Neutrons/***Induced Fissioner Menu***

Allows the selection of one of four nuclides that can be induced to fission by incident neutrons. The four nuclides are U-235, U-233, Pu-239, and Np-237. Because the neutron yield from fission depends on the incident energy of the neutron inducing the fission, five choices (1.00, 1.25, 1.50, 1.75, and 2.00) for the average incident neutron energy are given for U-235, Pu-239, and Np-237. Some guidance on the choice is provided by the ratio of the front to back detector counts because the ratio is expected to be smaller for fast neutrons. The default is Pu-239 (2.00 MeV), which is appropriate for the BeRP ball.

Box 2 in Figure 8

Rates and Uncertainties

These are the singles, doubles, triples, and quadruples determined in the processing of the data.

Box 3 in Figure 8

Gap Filter

Sets the maximum allowed number of consecutive bins with no events until all subsequent events are ignored in the processing. This allows cosmic ray events that may appear as isolated events on the right side of the Feynman histogram to be ignored. Figure 4 does not have any such events.

Lifetime

This is the average lifetime of neutrons in the MC-15 detector. The lifetime is calculated in the Plots/Rates screen (Figure 5).

Count Time

This is the duration time of the measurement read from the lmx file header. It cannot be changed on this screen.

Box 4 in Figure 8

Calculated Rates

These are the calculated rates from the Fits (Figure 5).

Box 5 in Figure 8

11) This is the main window in the program. Determine what parameters are known and unknown. Check the heading boxes for the groups of parameters that the program is to calculate. Enter the known parameter values in the other groups.

The parameters are grouped under the headings Detection, Primary Neutron Source, Multiplication, and Alpha Ratio. The analysis uses several equations that contain data from these groups. If data are known for some of these groups, the program will attempt to calculate the results for the others based on the processed data. Most commonly, if data is known for two of these groups, the program will attempt to calculate results for the other two based on the processed data. Most often, the leakage multiplication and the spontaneous fission rate are unknown, and this is the default situation shown in Figure 8. The

Detection parameters for input here are usually from the SNAP measurements and are discussed below in Row Ratio/SNAP III and Row Ratio/Transmission. If data are only known for one group, the program will use the triples data for the calculation, but the results may have large uncertainties because the triples usually also have large uncertainties.

Detection

Analysis/***Detection Check Box***

If this box is checked, the program will calculate the NSS, efficiency, and transmission based on other entered data. If the box is not checked, values must be entered in NSS or in efficiency and transmission.

Analysis/***Detection/NSS***

If the neutron source strength (NSS) is known and entered here, the efficiency, calculated rates, and all other parameters dependent on the source strength are recalculated and displayed in their respective locations. If NSS is left blank, the efficiency entered in the efficiency box is used to calculate all of the other parameters dependent on it. The Detection parameters for input here are usually from the SNAP measurements and are discussed below in Row Ratio/SNAP III and Row Ratio/Transmission.

Analysis/***Detection/efficiency***

Efficiency of the MC-15. At 50 cm, this is typically approximately 0.0l for a bare system. The MC-15 efficiency is different than the efficiency of the SNAP discussed below in Row Ratio/Transmission.

Analysis/***Detection/transmission***

Neutron transmission through any material between the source and the MC-15. This is based on the SNAP measurements and is discussed below in Row Ratio/SNAP III and Row/Transmission.

Primary Neutron Source

Analysis/***Primary Neutron Source Check Box***

If this box is checked, the program will calculate the mass in grams and the fissions/sec based on other entered data. The default value for the enrichment is 6.00%, but this can be changed manually based on known information. If the box is not checked, values must be entered for the mass and fissions/sec.

Analysis/***Primary Neutron Source/grams***

Total mass of the neutron source in grams.

Analysis/***Primary Neutron Source/ fissions / sec***

Fissions per second in the primary neutron source.

Analysis/***Primary Neutron Source/Enrichment***

Percentage of primary starter isotope, e.g. 6% Pu240 in Pu. The default value is 6.00% but may be changed.

Multiplication

Analysis/***Multiplication Check Box***

If the box is checked, the program will calculate the leakage and total multiplication, and this is the usual choice. If the box is not checked, the multiplications must be entered.

Analysis/***Multiplication/Leakage***

Neutron leakage multiplication for the source.

Analysis/***Multiplication/Total***

Neutron total multiplication for the source.

Alpha Ratio

Analysis/***Alpha Ratio Check Box***

If the box is checked, the program will calculate the alpha ratio and the neutrons per second from (alpha,n) reactions based on other entered data. If the box is not checked, a value for the alpha ratio should be entered.

Analysis/***Alpha Ratio***

Ratio of neutron rates from (alpha,n) reactions to the starter neutrons in the source. This ratio should be zero for a metal source such as the BeRP ball.

Box 6 in Figure 8

Analysis/***Best Solutions(s)***

This box lists the total multiplication, efficiency, mass of the primary neutron source, the total mass, the alpha ratio, and the chi squared for the fit to the data for the best solution(s).

Analysis/***All Possible Solutions***

This box lists the total multiplication, efficiency, mass of the primary neutron source, the total mass, the alpha ratio, and the chi squared for the fit to the data for all mathematically possible solutions. The chi square may be smaller for some solutions, but they may be unphysical, e.g., with a negative mass.

Contours

This tab allows the exploration of a range of possible solutions, which may be helpful if the results seem anomalous. Figure 9 with the Mve tab selected shows a plot of the MC-15 efficiency vs. the total multiplicity. Figure 10 with the Mvm tab selected shows of the mass vs. the total multiplicity. The bottom of the screens allows the setting of limits on some of the parameters, selection of which parameters to hold fixed, the number of rates and lifetimes, and the Fit Offset. After these choices are made, clicking the Find Solutions button will generate the plots shown in Figures 9 and 10. However, note that the response may take one or two minutes because of the large number of calculations required. Clicking on one of the plots with will position horizontal and vertical lines that cross on the curve to make it easier to read the values on the axes. The lines can be moved by clicking at different positions on the plots.

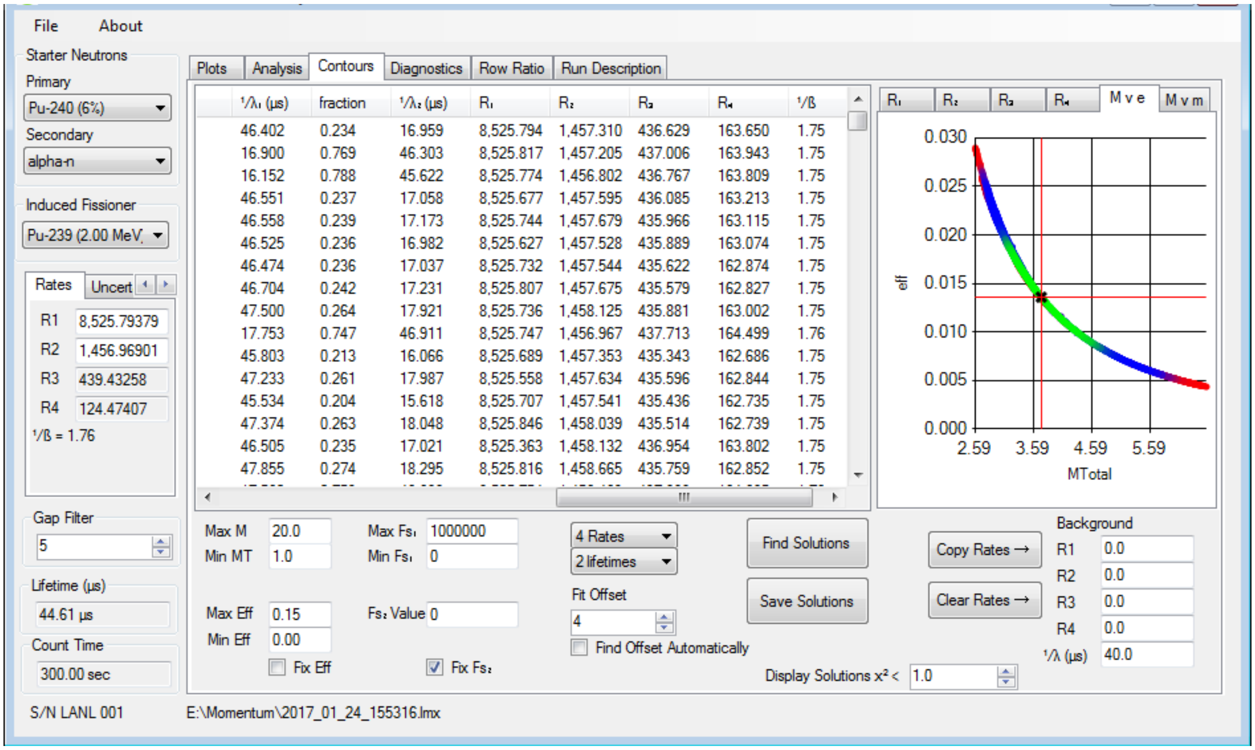

Figure 9. Example of screen with Contour and Mve tabs selected.

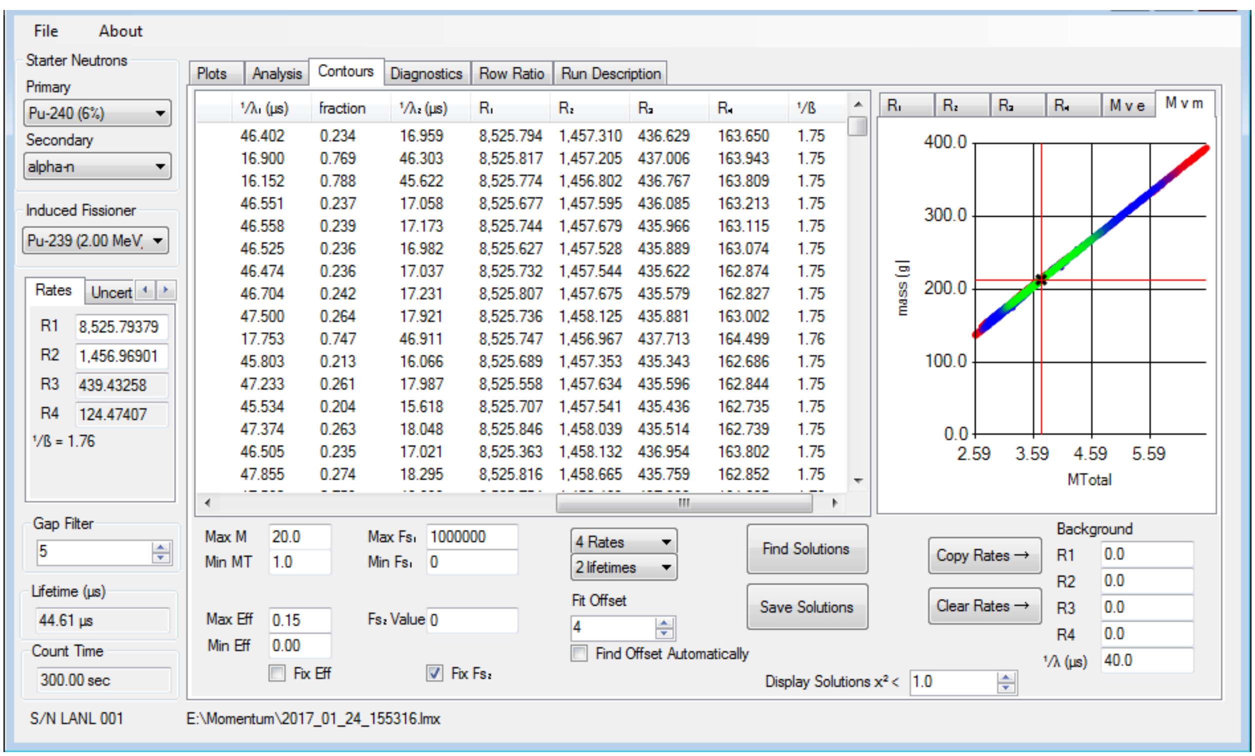

Figure 10. Example of screen with Contour and Mvm tabs selected.

Diagnostics

The singles, doubles, triples, and quadruples for the primary and secondary starter neutrons and for the induced fissioner are listed.

Row Ratio

12) Select the Row Ratio tab.

Row Ratio/*Multiplicity*

13) Under the Multiplicity tab, select the detector (Detector 1 or Detector 2) in the menu bar above the Tube-Counts window and select the Tube Layout. Uncheck any tubes that appear anomalous.

Figure 11 shows an example of the Multiplicity window and Radar Plot after the detector is selected in the menu bar above the Tube-Counts window and the Tube Layout is selected. The detector menu bar allows selection of Detector 1, and also Detector 2 if there are two MC-15 Detectors. The Tube Layout box allows selection of the MC-15, nPod, or unspecified. The selection controls the list of detectors displayed, the row ratios, and the radar and bar plots. Unchecking boxes in the list of detectors removes data for those detectors from the Row Ratio calculations and displays red points or bars for these detectors in the plots.

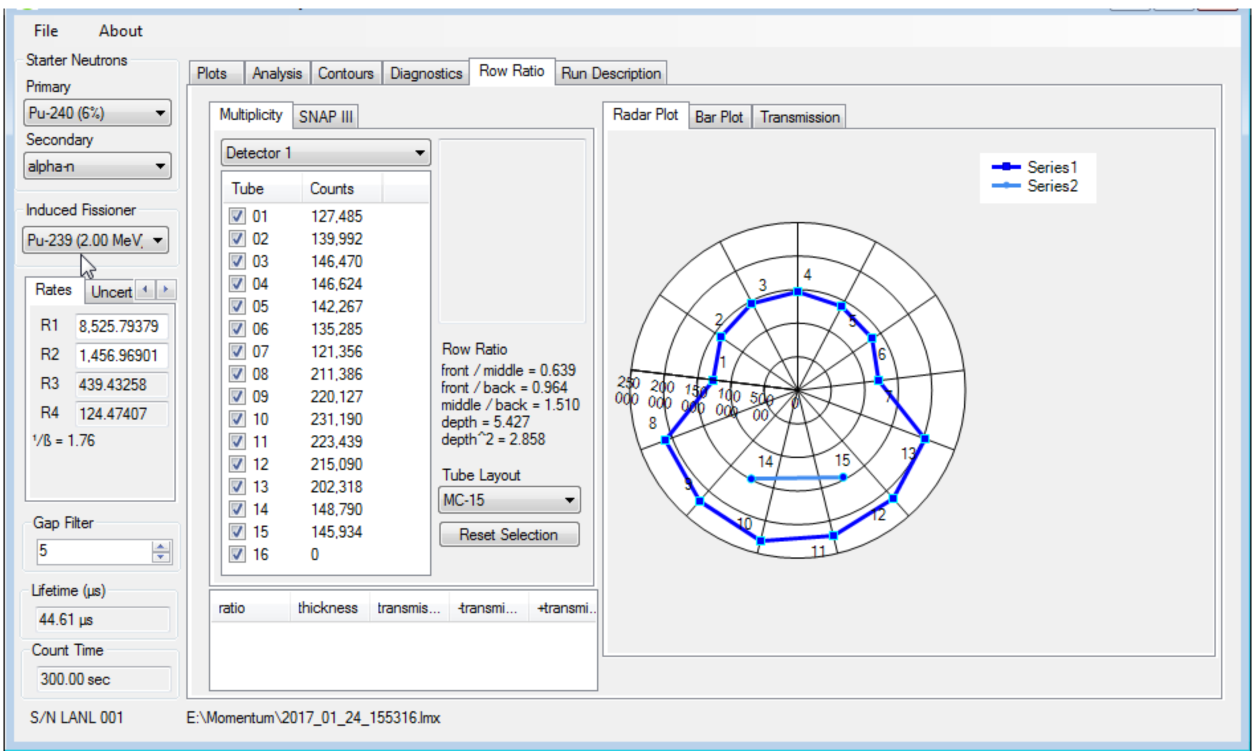

Figure 11. Screen showing the Tube Counts and Row Ratios in the Multiplicity window and the Radar Plot.

14) **Open the SNAP III and Transmission tabs.**

15) **Under the SNAP III tab, enter the counts and time without and with poly. Also enter the source to SNAP detector distance (S to D) and the reflector to SNAP detector distance (R to D). Under the Transmission tab, select the detector (only nPod is available in the present version of the software) and the moderator Polyethylene (HDPE), PBX-9404, or PBX-9402.**

16) **Click on the Nss to Analysis button to transfer the Nss and transmission values to the Analysis screen (Figure 8).**

Results under the Row Ratio tab are shown in Figure 12. The transmission = 1 in this example because the BeRP ball was bare.

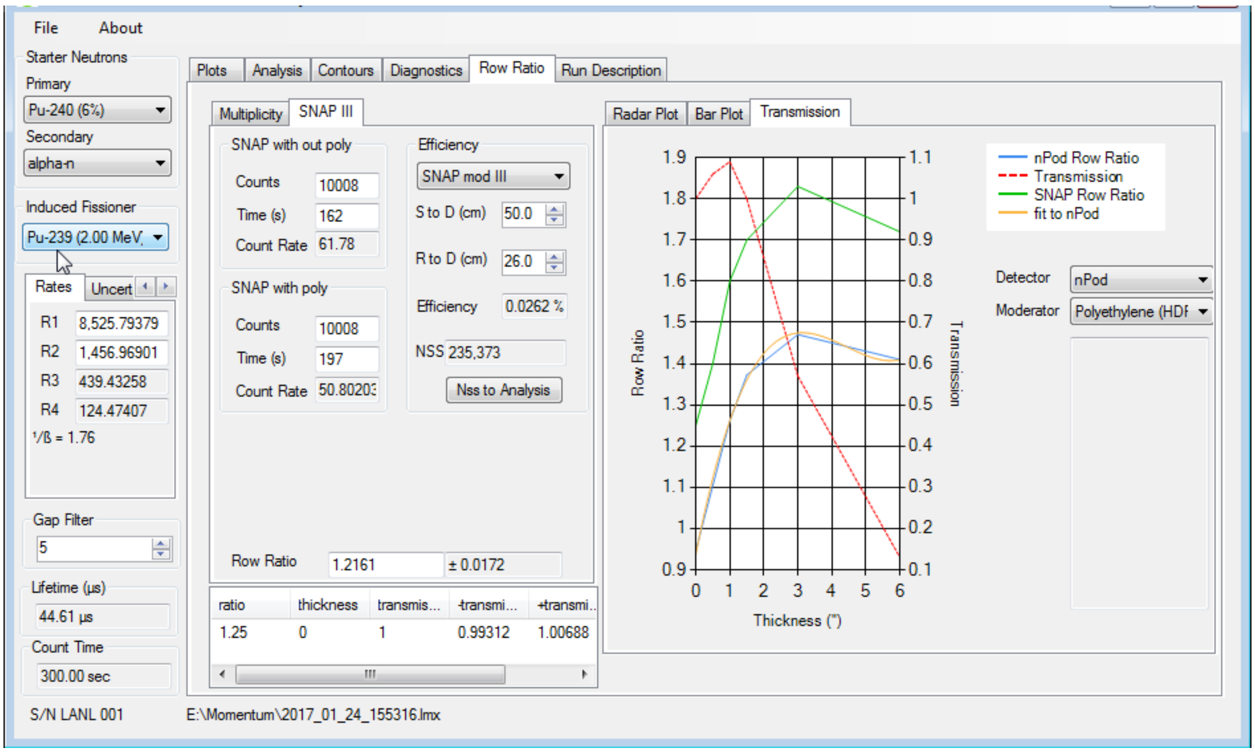

Figure 12. Screen showing the SNAP and transmission data.

The use of SNAP data to determine NSS and the transmission depends on previous calibration of the SNAP. The Momentum software contains a table of the SNAP efficiency as a function of the source to detector distance and the reflector (usually the floor) to detector distance. This is used to calculate the NSS with the following equation.

$$NSS = \frac{C^0_{SNAP}}{T^0_{SNAP}} \times \frac{1}{\varepsilon_{SNAP}}$$

NSS = neutrons per second emitted from the surface of the special nuclear material (SNM) if there is no shielding around the SNM. If there is shielding around the SNM, it is the neutrons per second emitted from the surface of the shielding.

C_{SNAP}^{0} = SNAP Counts with no poly on the SNAP

T_{SNAP}^{0} = SNAP Time (s) with no poly on the SNAP

ε_{SNAP} = SNAP efficiency interpolated in the SNAP lookup table

The SNAP ratio of the counting rate without and with poly on the SNAP as a function of the thickness of the thickness of the moderator (shielding) around the SNM has also been calibrated. This calibration curve is the green curve shown under the Transmission tab and is labeled as SNAP Row Ratio in the legend. The software uses this curve to determine the moderator thickness. In Figure 12, this is zero because the BeRP ball is bare. Then the software uses the red curve, which is the transmission as a function of moderator thickness, to determine the transmission. In Figure 12, again this is 1.00 because the BeRP ball is bare. Note that the moderator thickness might be known from a radiograph. Then the transmission could be read from the red curve and manually entered in the Analysis screen (Figure 8).

The MC-15 efficiency in the Analysis screen (Figure 8) is different than the SNAP efficiency. Pushing the Nss to Analysis button only transfers the NSS and transmission to the Analysis screen. The software uses the following equation to calculate the MC-15 efficiency.

$$\varepsilon_{MC-15} = \frac{R_{1\ MC-15}}{NSS} \times \psi$$

ε_{MC-15} = fraction of the number of neutron per second being generated by fission, (α,n) reactions, etc. and emitted from the surface of the SNM that are detected by the MC-15

$R_{1\ MC-15}$ = Singles counting rate in the MC-15

NSS = neutrons per second emitted from the surface of the special nuclear material (SNM) if there is no shielding around the SNM. If there is shielding around the SNM, it is the neutrons per second emitted from the surface of the shielding.

$\psi = \text{transmission through any moderator (shielding)around the SNM. If there is no moderator,}$ $\psi = 1.00.$

Run Description

Detailed information about the run from the .lmx file is shown (Figure 13).

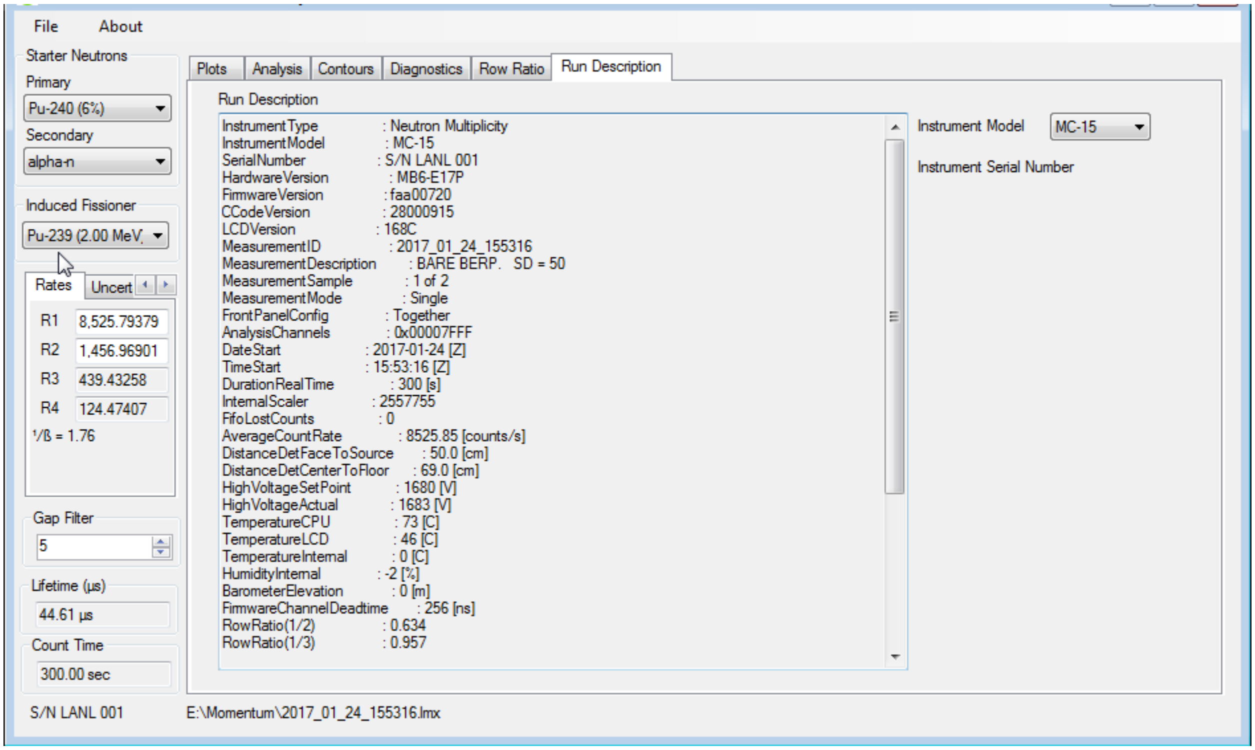

Figure 13. Example of the Run Description data.

Results

17) View the results in the updated Analysis screen (Figure 14).

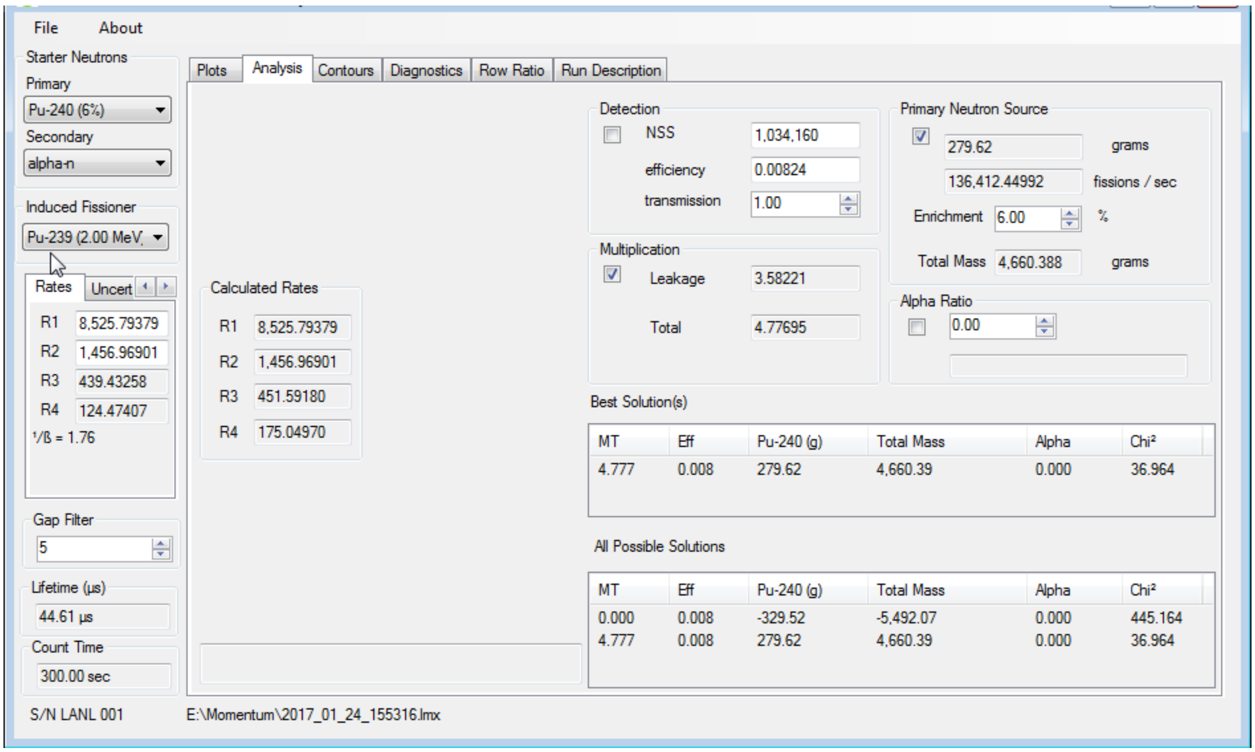

Figure 14. Final Analysis screen with results.

The leakage and total multiplication, mass of the fissioning isotope, fission/sec, and total mass were determined. These are most often the parameters to be determined by analysis with Momentum. The Total Mass of 4.66 kg is close to the known mass of 4.5 kg for the BeRP ball.

Examples

Passive Measurement of Bare BeRP Ball

The previous detailed discussion in this manual used the bare BeRP ball as an example. Three key figures, Figures 15, 16, and 17 below, are repeated here to provide a short summary of the analysis for this example.

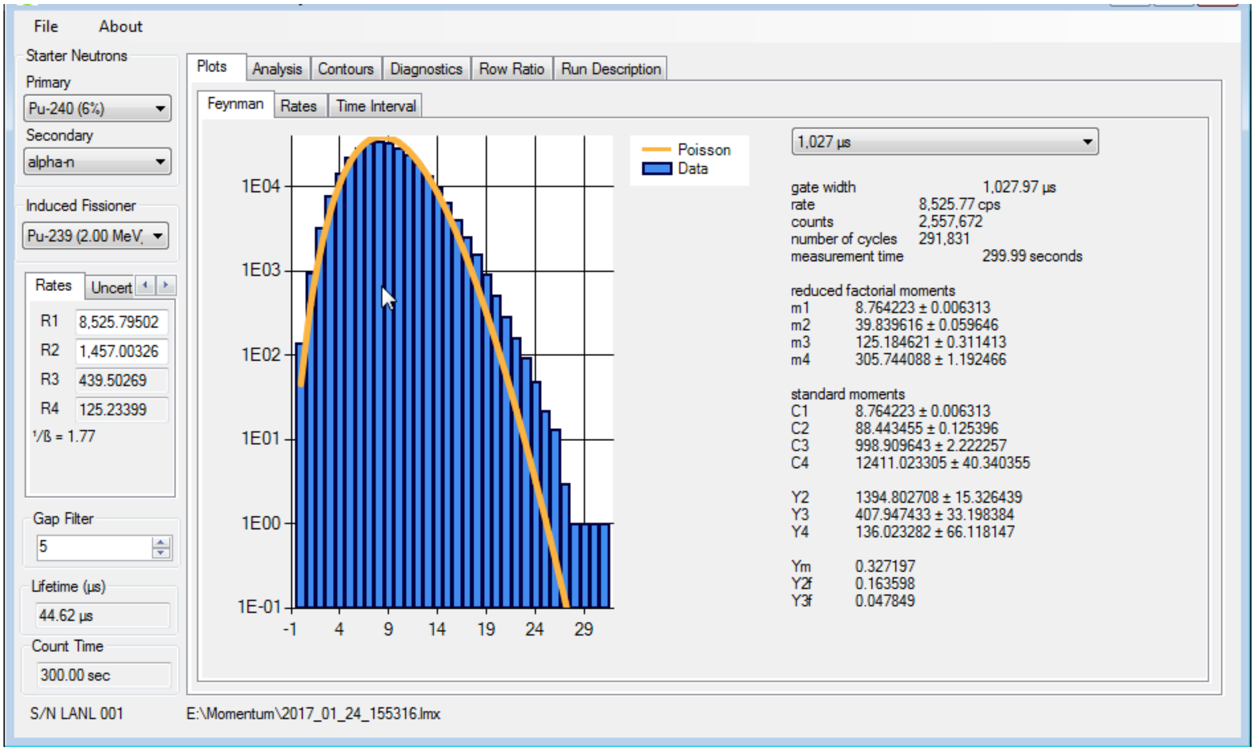

Figure 15. Screen after the BeRP ball data is processed.

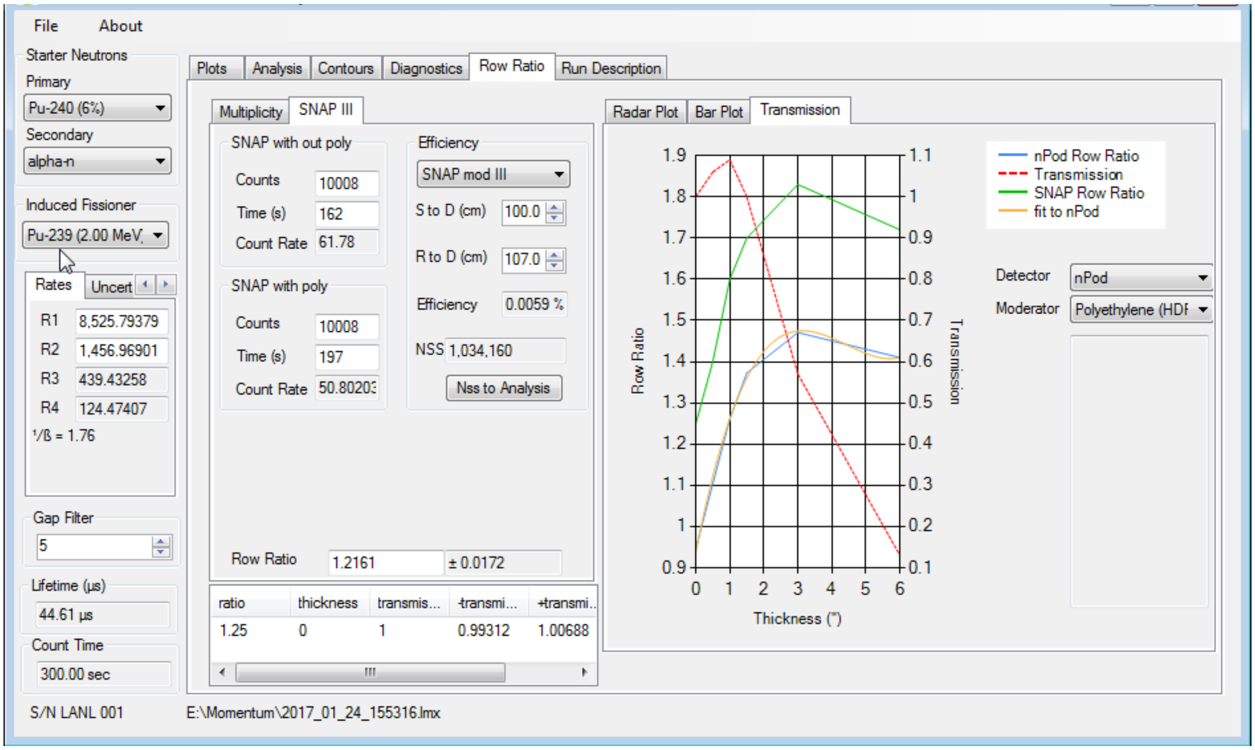

Figure 16. Row Ratio screen showing BeRP ball SNAP parameters.

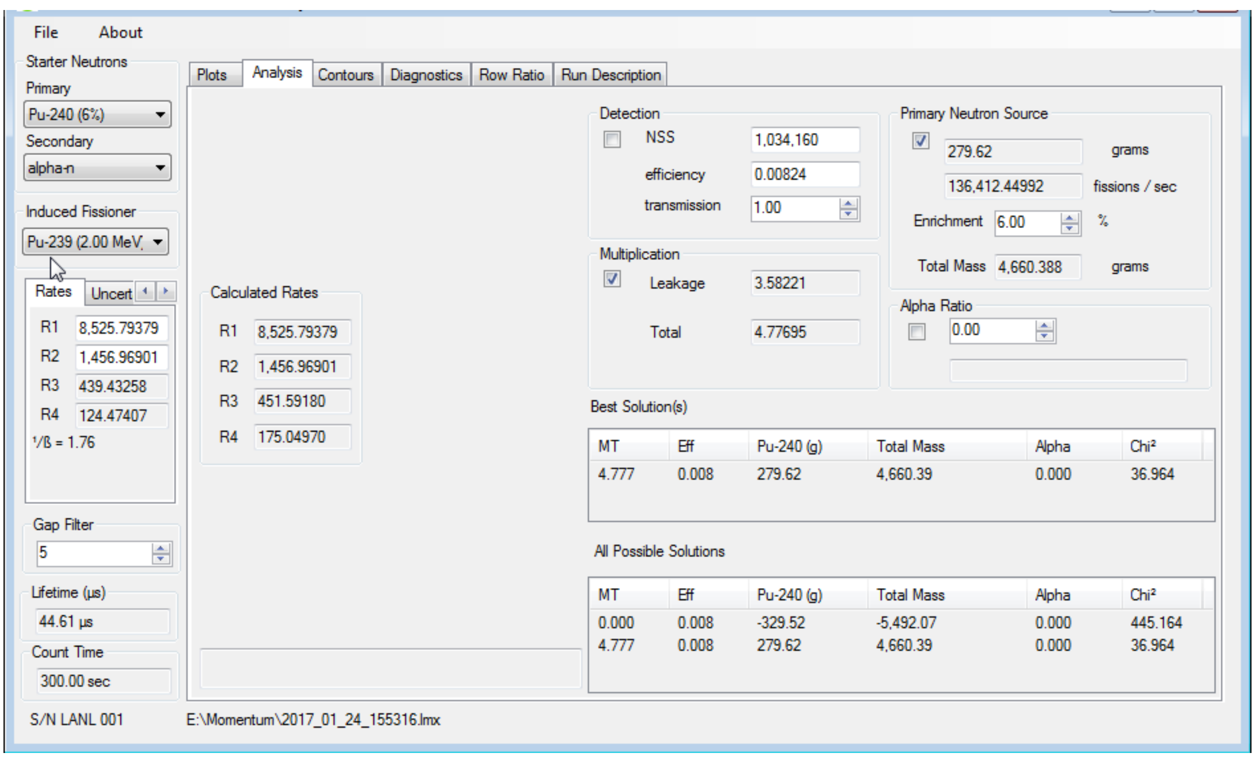

Figure 17. Final Analysis screen showing the BeRP ball results.

Passive Measurement of ^{252}Cf inside HDPE Shells

Figure 18 shows the screen after the .lmx file is opened. All of the segment events the tube counts look normal. The count rates in the front and middle tubes are almost equal, which means that the number of slow neutrons and fast neutrons are almost equal. The count rate is stable with time.

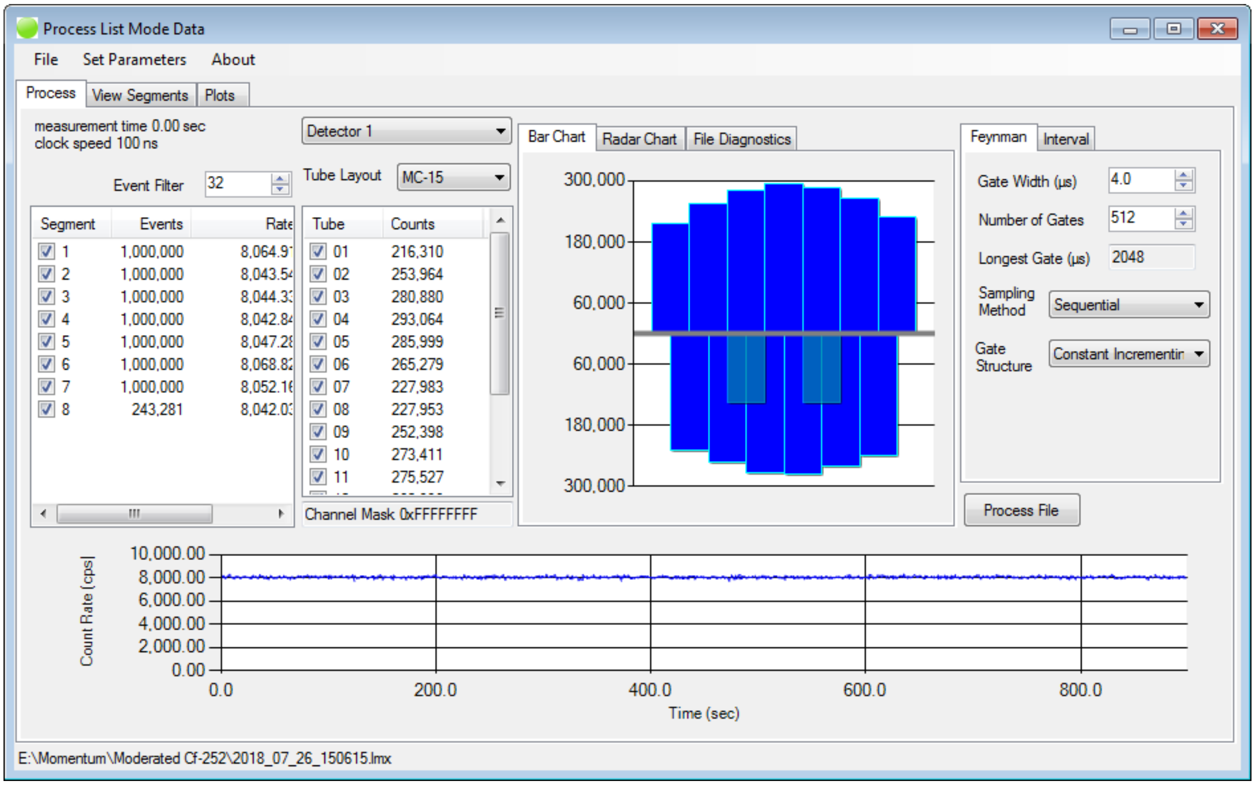

Figure 18. First screen after the ^{252}Cf .lmx file is opened.

Figure 19 shows the screen after the file has been processed and the starter neutrons selected. The selection of the induced fissioner does not affect the final multiplication and mass. The fact that the Feynman histogram closely follows the Poisson distribution means that there is little multiplication.

Figure 20 shows the fit to the doubles to determine the detector lifetime. The fit is good with two lifetimes and an offset of zero.

Figure 21 shows the Row Ratio screen after the SNAP data has been entered and the moderator has been selected.

Figure 22 shows the final results. The mass is 134 ng of ^{252}Cf, and the multiplication is 1.00 as expected.

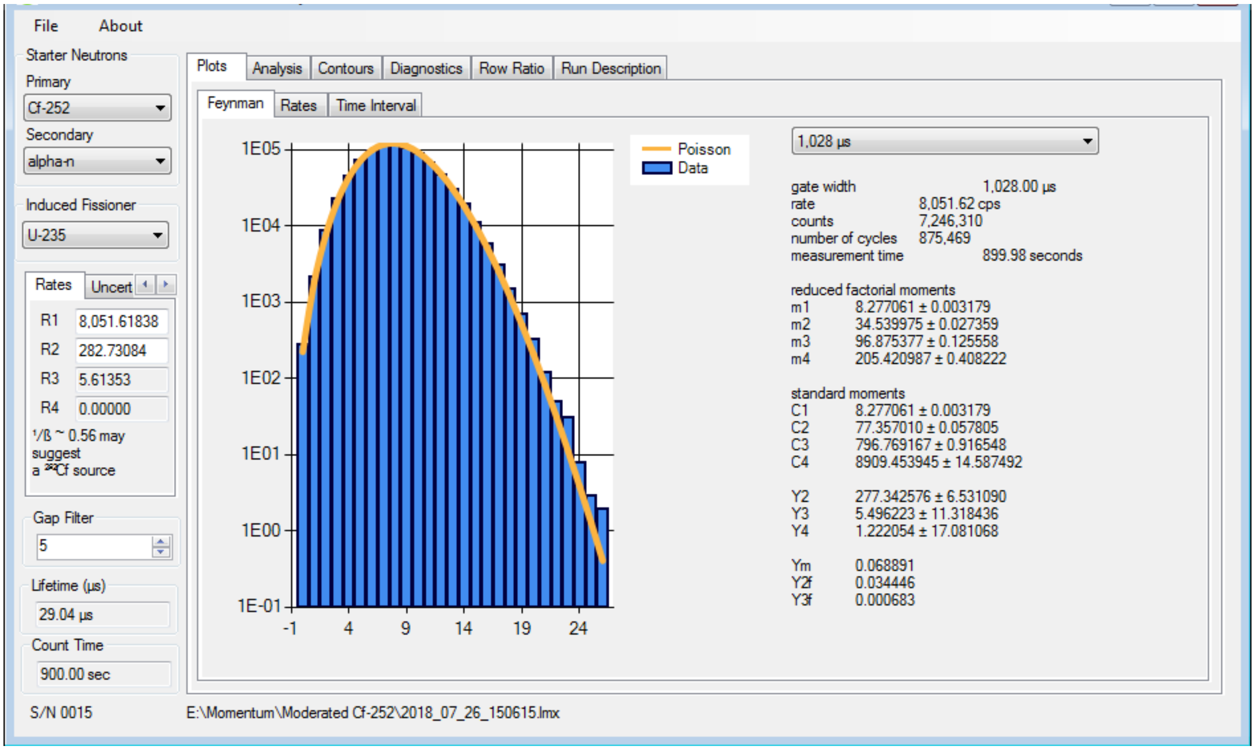

Figure 19. Screen after the ^{252}Cf file has been processed and the starter neutrons selected.

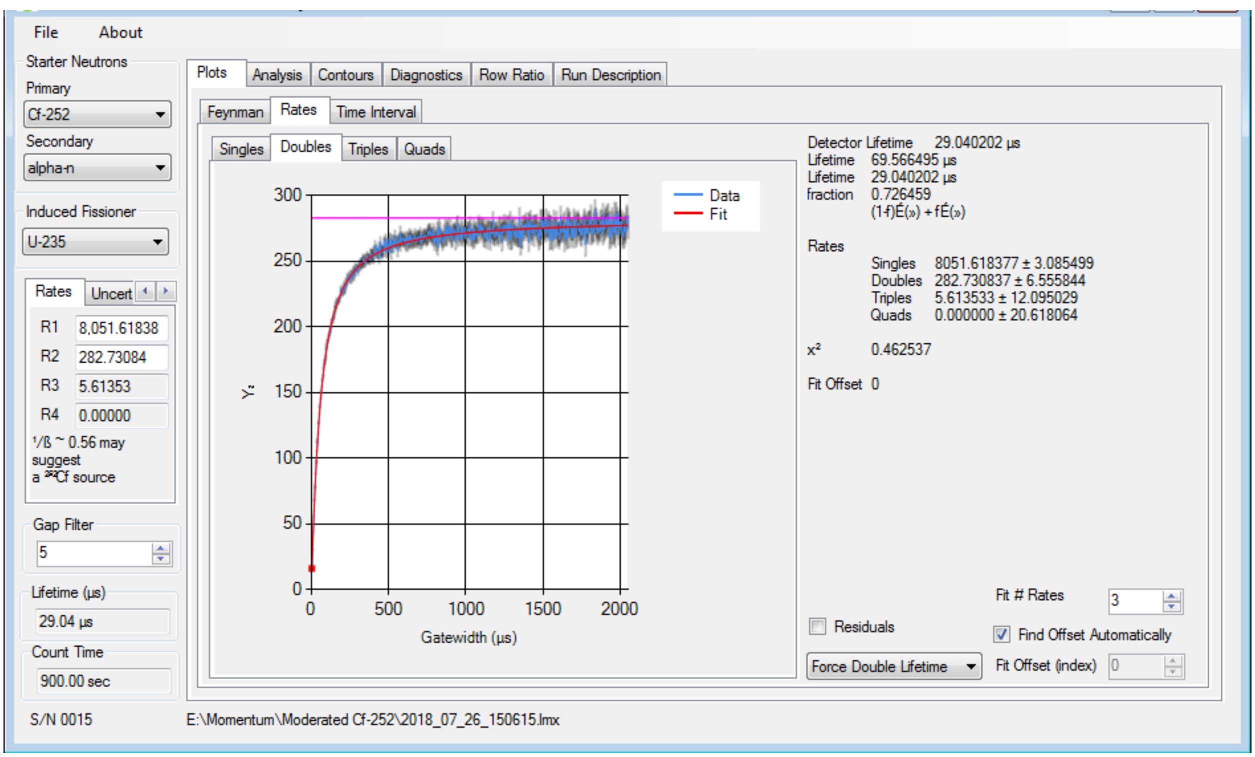

Figure 20. Screen showing the fit to the ^{252}Cf doubles to determine the detector lifetime.

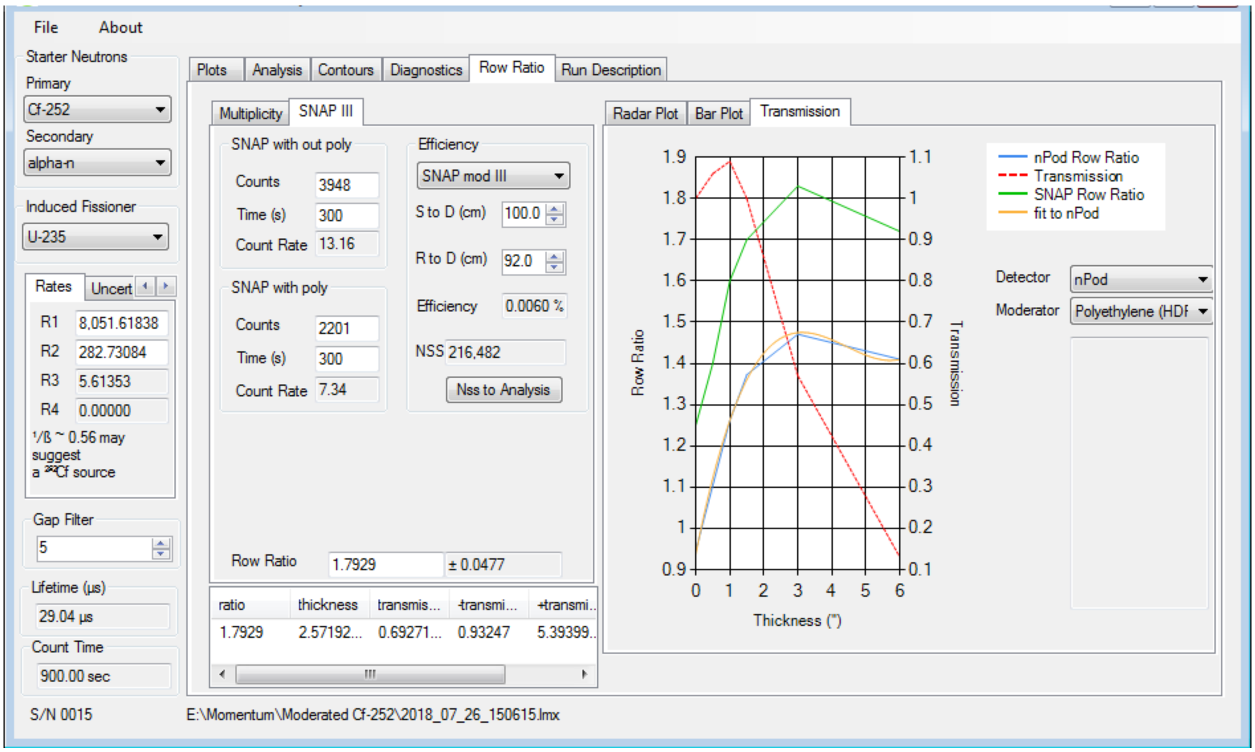

Figure 21. Screen showing the ^{252}Cf SNAP parameters.

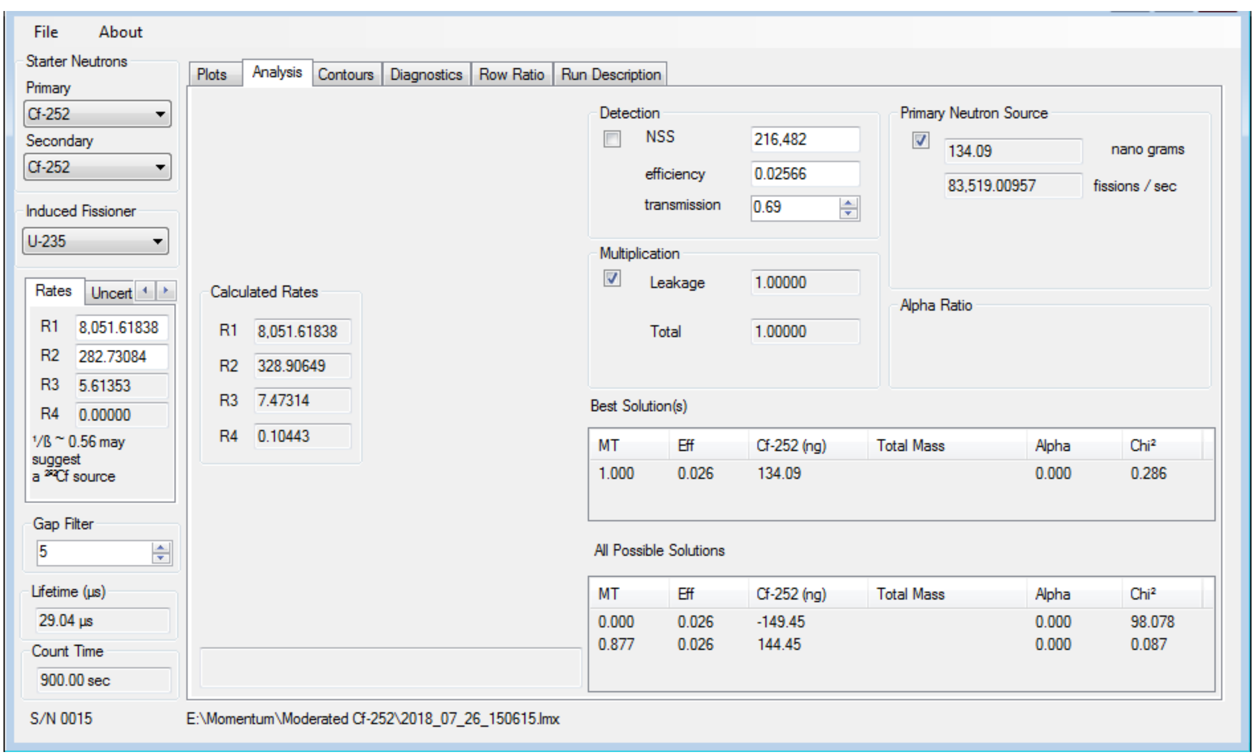

Figure 22. Screen showing the ^{252}Cf final results.

Active Measurement of MARVEL HEU disks with 2 MC-15s

The data were first analyzed with the code Feynman to select data between the neutron generator pulses and create a .xml file. Figure 23 shows the first screen after the .xml file from generated by the Feynman code was opened in Momentum and the correct Starter Neutrons for an active measurement were entered. The fact that the Feynman histogram is higher than the Poisson distribution on the right in Figure 23 indicates multiplication. Figure 24 shows the Row Ratio screen after the SNAP data has been entered and the Moderator has been selected. Figure 25 shows the final Analysis with the results. The calculated total multiplication is 3.42. Simulations gave 3.03, which might be low because reflections in the present setup from the neutron generator, support platform, floor, and MC-15s were not included.

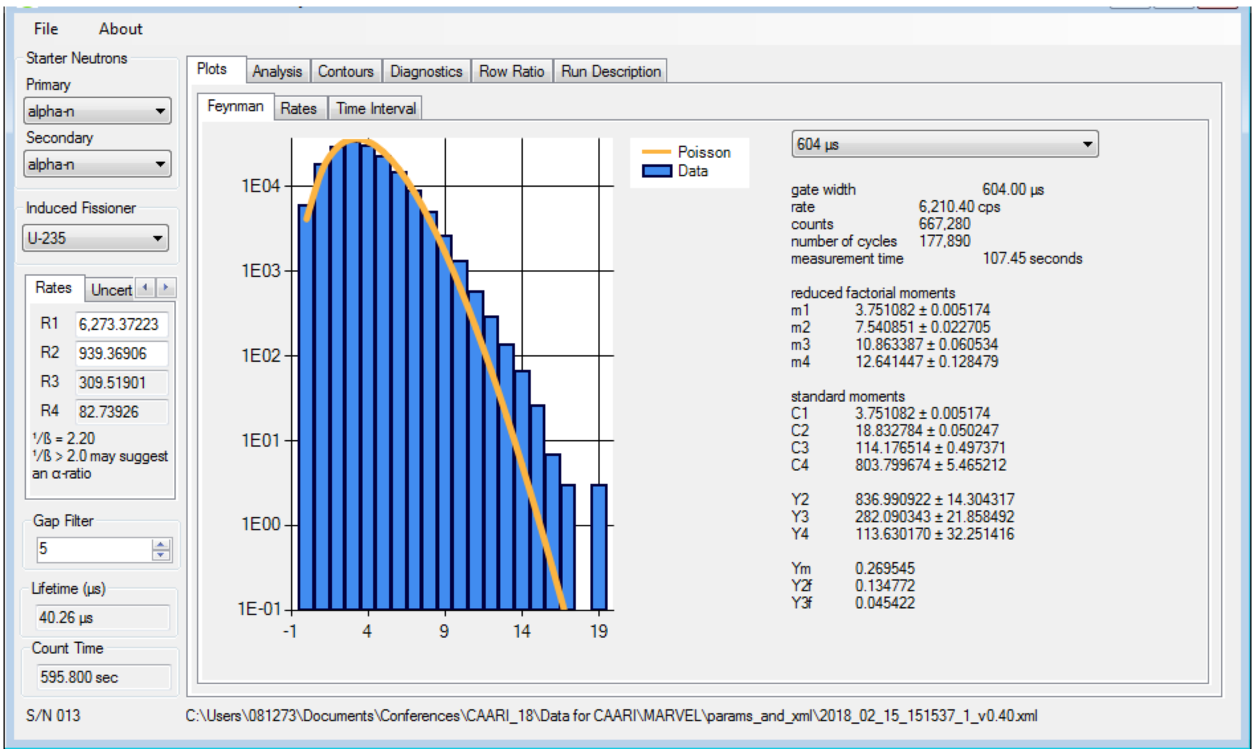

Figure 23. First screen after the MARVEL .xml file is opened.

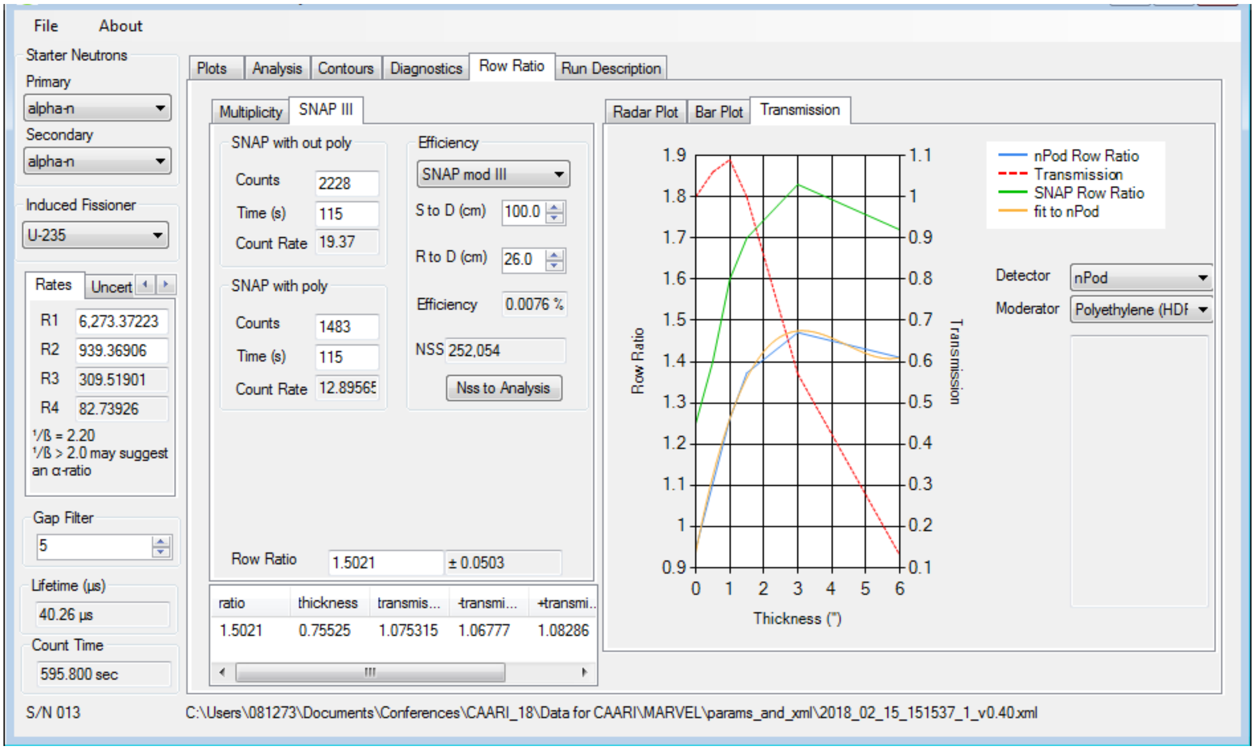

Figure 24. Row Ratio screen showing the MARVEL SNAP parameters.

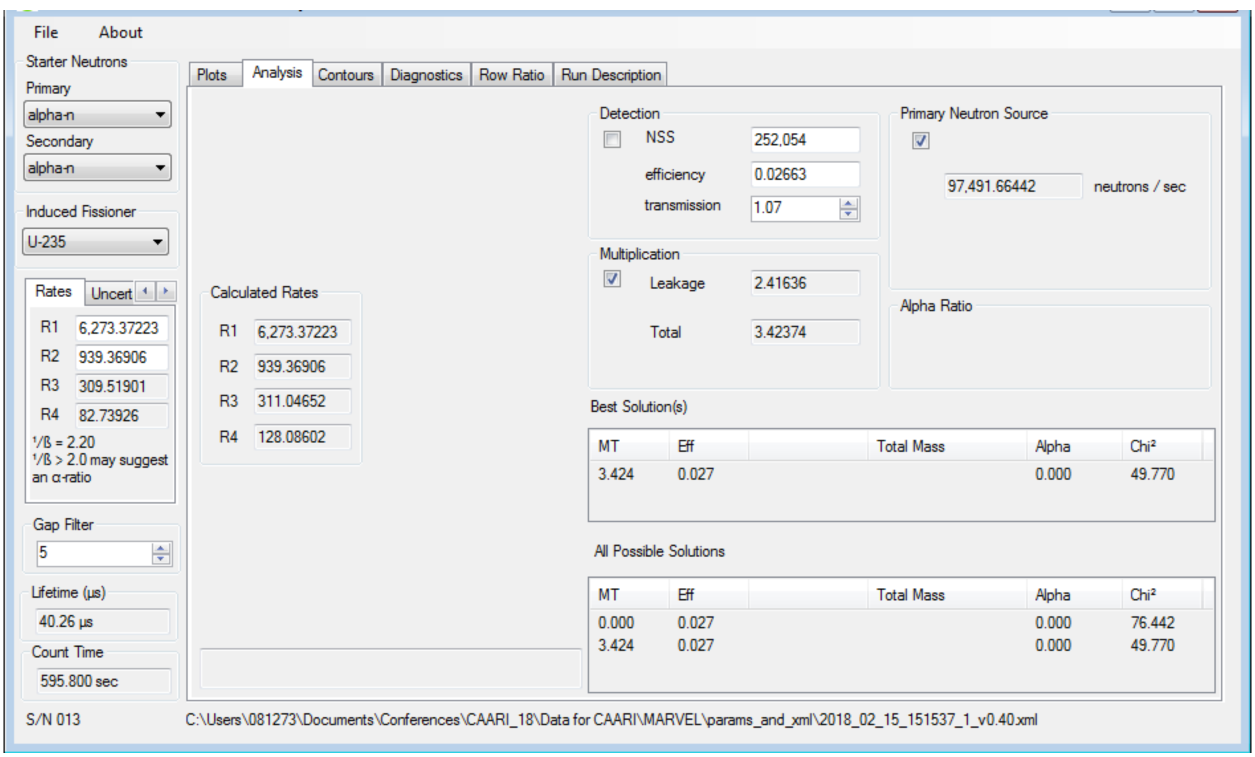

Figure 25. Final Analysis screen showing the MARVEL results.

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